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Pyrolysis of wood waste containing urea-formaldehyde and melamine-formaldehyde resins

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Abstract

Nowadays, wood industry produces huge amounts of wood waste containing various additives. Wood waste containing urea-formaldehyde (UF) and melamine-formaldehyde (MF) resins such as particleboard or laminated flooring constitutes a consequent resource of energy. However, this type of waste needs a ‘‘refinement’’ to eliminate nitrogen responsible of the production of pollutants. The pyrolysis of particleboard and flooring at low temperature (523–573 K) has been studied on an experimental reactor which allows controlling mainly parameters of the pyrolysis such as temperature, reaction atmosphere or residence time of gases in reactor. Some optimum couples ‘‘time/temperature’’ of treatment are determined by FTIR analysis of the gas products. Quantities of CO, CO_2, NH_3 produced during the treatment are evaluated in order to estimate the performance of the process. Elementary analyses of residues allow validating the previous results. Thermal analyses of residues in a calorimetric bomb enable to evaluate the energy efficiency of the process.

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Keywords: Pyrolysis; Wood waste; Urea-formaldehyde; Melamine-formaldehyde; FTIR analysis

1. Introduction

In the context of global warming and problems of production of energy, the gasification of biomass has a promising future as an alternative to produce energy. However, this way to produce energy is today unprofitable because of the high price of the raw materials such as wood chips for example. The idea is to use wood waste containing urea-formaldehyde (UF) and melamine-formaldehyde (MF) resins (such as particleboard or laminated flooring) as raw materials to produce energy. These wastes present the advantage of having a negative cost but needs to be ‘‘refined’’. Indeed, the nitrogen coming from UF and MF resins [1] is responsible for production of ammonia, isocyanic acid, cyanhydric acid and nitric oxides during a classical thermal valorisation (combustion or gasification) [2,3].

The pyrolysis of biomass has been well studied [4–7] but no model could be clearly established because of the great variability of the resource and the operating conditions (temperature, reaction atmosphere, transfer of mass and heat). We can note however that from 473 to 553 K, physical properties of wood change, what is the phase known as torrefaction. The production of CO is observed then, CO_2, acetic and formic acid, methanol and water coming from the decomposition of hemicelluloses [4–7]. From 553 to 773 K, it is the phase of carbonization where condensable gases (acid acetic and formic, methanol, tar) and non-condensable (CO, CO_2, H_2, C_xH_y) are produced. An exothermic decomposition of cellulose (553–653 K) is noticed followed by endothermic reactions (from 653 to 773 K) of depolymerizations and recombinations within the structure of lignin.

Concerning wood waste degradation, several works are proposed in the literature. Pyrolysis of CCA-treated wood (CCA is a wood preservative solution composed of chrome, copper and arsenic which causes some problems of heavy metals volatilisation during thermal valorisation) has been well studied by [10,11]. A study of the kinetics of pyrolysis of five kinds of wood waste (forest, demolition, machines, furniture, pallets) has been carried out by [12] using models proposed by [13,14]. The works of [15,8] aim at describing degradation of creosote-treated waste. Concerning melaminated particleboard which contains aminoplasts resins (urea-formaldehyde, melamine-formaldehyde), literature gives little information. Some works [8,9] show

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that pyrolysis of these resins produces methanol, formaldehyde, carbon dioxide, and some nitrogen compounds such as ammonia, and acid isocyanic and cyanhydric.

This work deals with a thermal pre-treatment, by a low temperature pyrolysis, of wood waste in order to produce a "clean" and cheap raw material for a gasification unit. This work aims at evaluating and optimising the efficiency of the thermal pre-treatment in terms of nitrogen elimination and energy recovery.

2. Experimental

2.1. Samples preparation

The samples are prepared from industrial particleboard and laminated flooring which have been crushed. The wood and resins samples were the same as the constituents of the particleboard. The size of the particles is lower than 1 mm. The samples were dried in an oven for 4 h at 376 K before the experiments were performed. Table 1 shows the wood, the particleboard and the laminated flooring elementary analysis realized in the Analysis Central Service of CNRS in France. The particleboard manufacture gives us an approximate constitution of the particleboard. The composition in wt% (on dry mass) of each component is: wood (88–90%), UF resin (10–12%), MF resin (less than 0.5%). We do not have more information about laminated flooring, except that its proportion of MF resin is more important.

2.2. Equipment and procedure

2.2.1. Description of the laboratory device

The experiments were carried out in a quartz tubular reactor (Fig. 1) placed in a horizontal furnace. A quartz sample box enables the insertion of waste (a few grams maximum) in the reactor whose temperature can reach 1373 K. This characteristic of the device allows carrying out experiments in conditions of fast pyrolysis what is not possible in a thermobalance. An automatic system of insertion enables to choose the speed of introduction and the position of the sample box in the furnace. The device is fed with a gas flow controlled by flow controller allowing the introduction of the appropriate gas mixture (nitrogen in this work). The variation of the position of the sample box in the furnace, the gas flow and the diameter of the tubular reactor enable to control the residence time of the gases in the device.

The gases resulting from the pyrolysis of waste go through the 135 mL gas cell (10 cm path length) of the FTIR spectrometer (Bruker Equinox 55) where they are analysed in a semi-continuous way (time of sampling: 15 s.). The configuration of the FTIR spectrometer (resolution of 2 cm^{-1}, five scans per measure) allows a qualitative analysis of many compounds: carbon dioxide and monoxide, methane, light hydrocarbons (ethane, ethylene, etc.), N-compounds (ammonia, iscocyanic and cyanhydric acid), methanol, formic and acetic acid. A quantitative analysis method has been developed to evaluate the volume of CO, CO_2, CH_4 and ammonia produced during experiments.

Preliminary thermogravimetric experiments were performed on a Setaram Setsys 12 instrument, measuring samples of 100 mg under nitrogen flow of 90 mL/min, heating from room temperature to 343 K at a heating rate of 20 K/min, then after a holding time of 5 min to 1173 K at a heating rate of 1.5 K/min.

Table 1
Elementary analysis of wood and of particleboard

wt% (dry basis)	C	H	O	N
Wood	50.5	5.9	43.5	0.1
Particleboard	47.2	5.8	43.1	5.4
Flooring	46.4	5.8	42.1	6.1

2.2.2. FTIR quantitative analysis method

The FTIR spectrometer is regularly calibrated for CO, CO_2, CH_4 and NH_3 between 0% and 2%. The FTIR spectrometer is not calibrated for isocyanic acid (HCNO) because no standard is available for it. The characteristic frequencies used for the quantitative analysis was 2048–2053 cm^{-1} for carbon monoxide, 718–722 cm^{-1} for carbon dioxide, 2945–2950 cm^{-1} for methane and, finally, 955–970 cm^{-1} for ammonia.

The values of concentrations of the different gases in function of time are recorded in an excel table. The volume of gas produced during an experiment is obtained with the following expression:

$$V(\mathrm{X}) = \sum_{i}^{n} \left(\frac{C_i(\mathrm{X}) + C_{i+1}(\mathrm{X})}{200} Q_{\mathrm{N}_2} t \right) \tag{1}$$

with $V(\mathrm{X})$ is the volume of the gas X produced during the experiment (mL), n the number of measures during the experiment, $C_i(\mathrm{X})$ the concentration of the gas X for the ith measure given by FTIR analyses (%), Q_{N_2} the flow of nitrogen (mL/min) (considering that the flow of produced gases is negligible) and t is the sampling time (min).

2.2.3. Determination of the optimum duration of treatment in function of the temperature

First, this study aims to determine the optimum duration times necessary for each treatment temperature (set at the time necessary for the level of HNCO to reach a value lower than 3% of the maximum value reached in all tests).

In a second time, the purpose of this study is to evaluate the volumes of CO, CO_2, CH_4, NH_3 produced during each treatment and to characterize the residues.

Nitrogen flow is set at 2 L/min for particleboards experiments and 1 L/min for the flooring. The temperature of the furnace is fixed at the temperature of treatment (523, 533, 543, 553, 563 and 573 K). A 1 g sample is placed in the sample box. Once the sample has been set up, a short delay is necessary to purge the device in order to achieve a correct reference measurement with the spectrometer FTIR. The spectrometer FTIR records one spectrum every 15 s. The gas cell has a volume of 135 ml and is heated to 473 K to avoid any condensation which would damage the very sensitive windows

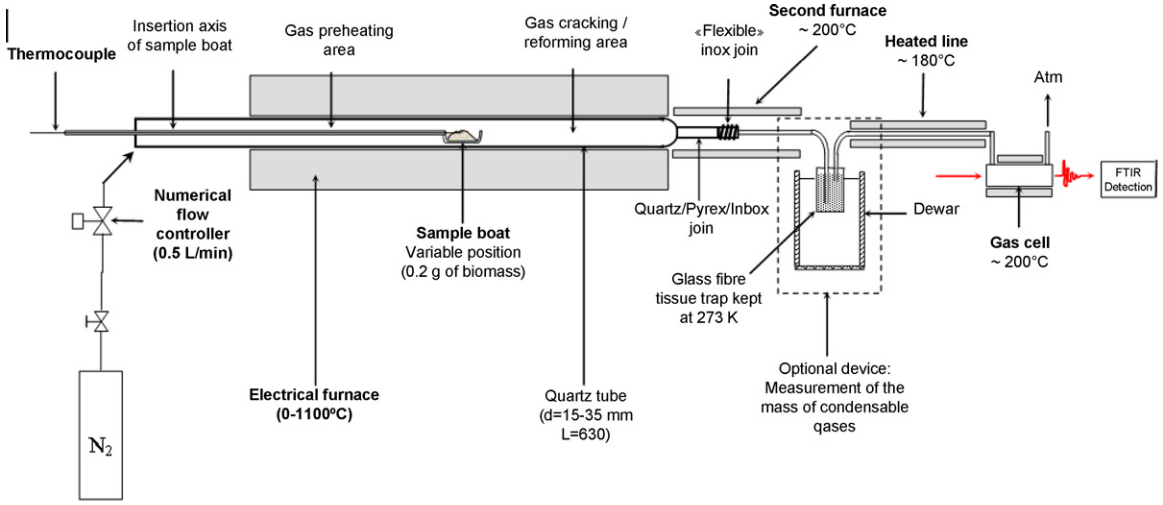
Thermocouple
Insertion axis of sample boat
Gas preheating area
Gas cracking / reforming area
«Flexible» inox join
Second furnace ~ 200°C
Heated line ~ 180°C
Atm
FTIR Detection
Numerical flow controller (0.5 L/min)
Sample boat Variable position (0.2 g of biomass)
Quartz/Pyrex/Inbox join
Dewar
Gas cell ~ 200°C
Glass fibre tissue trap kept at 273 K
Optional device: Measurement of the mass of condensable qases
Electrical furnace (0-1100ºC)
Quartz tube (d=15-35 mm L=630)
N2

Fig. 1. Sketch of the laboratory study device.

in KBr (potassium bromure). In order to determine optimum times of treatments, three 20 min tests are carried out for each temperature of treatment (523, 533, 543, 553, 563 and 573 K). The 80 recorded spectra are treated by the numerical quantification method. The evolution of the percentages of CO, CO_2, CH_4, NH_3 and HNCO are shown on Excel graphs.

2.2.4. *Characterisation of the residue*

The performance of the process is evaluated by means of elementary analysis of the residues. There are performed by a external laboratory. From a ‘‘nitrogen elimination’’ point of view, the more the degraded nitrogen level is significant, the more the waste is ‘‘cleaned’’. The calorific value of the sample after treatment has been determined in a calorimetric bomb.

3. Results and discussion

3.1. *Volatile product evolution under gradual heating measured in a thermobalance*

The DTG curves obtained are displayed in Fig. 2 showing the volatile product evolution from particleboard and from its pure components under the same conditions. In Fig. 2 the temperature range of wood degradation extends from 453 to 923 K where we can distinguish two flat peaks at the lower temperature range, and the maximum rate is reached at around 600 K. The temperature range of UF resin degradation extends from 450 to 730 K with three peaks at 498, 528 and 568 K. In the case of MF resin, the degradation extends from 600 to 1000 K with two peaks at 633 and 933 K. The shift between the temperature range of wood and of UF resin shows the opportunity of the selective pyrolysis of UF resin from waste. Indeed, between 523 and 573 K, the degradation of UF resin will be privileged while the degradation of wood will be limited. The selective desorption of MF resin in so low temperature conditions appears impossible. It does not represent a big problem since quantity of MF resin is very low in the samples.

Our TG and DTG curves are in accordance with the data of the literature [2,4,8,16–18] for wood, UF and MF resins. The peak temperatures are a bit higher than those presented by Hirata et al. applying a heating rate of 1 K/min [2]. The DTG curve of particleboard is close to that of wood because particleboard contains around 90% of wood. We can observe

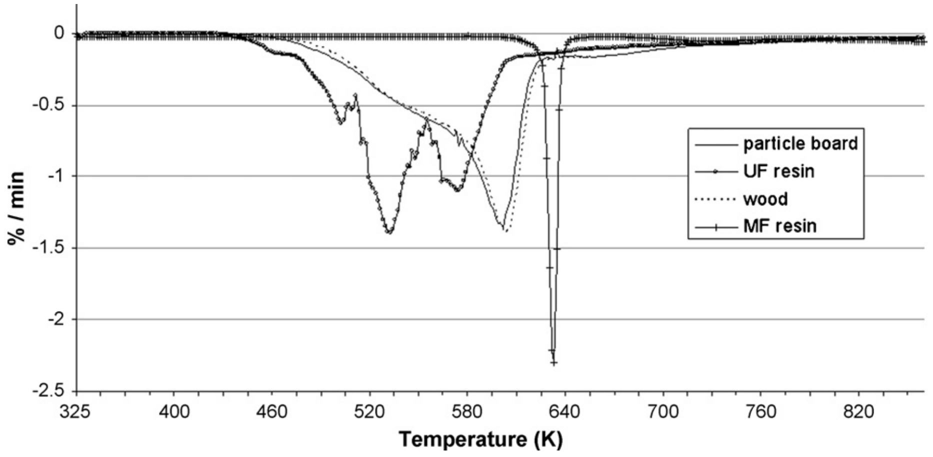

Fig. 2. DTG curves of particleboard and of its constituents; heating rate = 1.5 K/min under nitrogen.

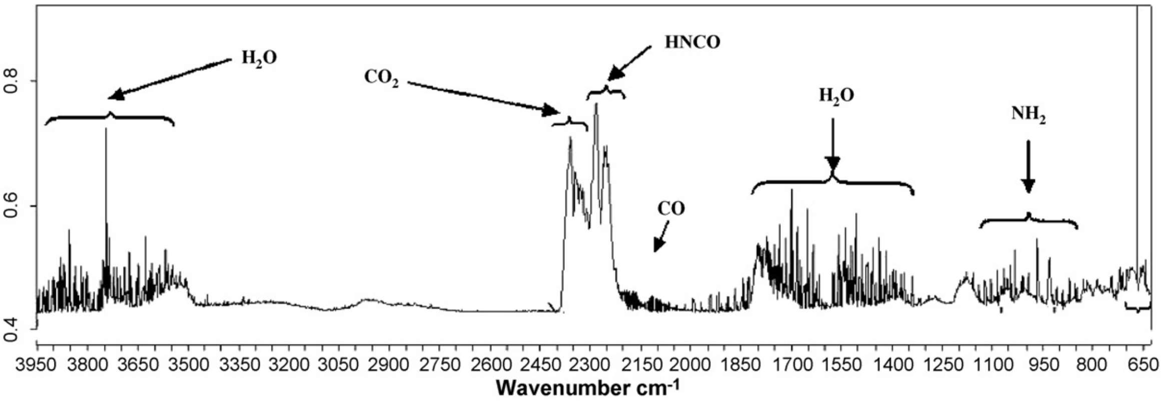

Fig. 3. IR spectrum of the mix carrier gas/pyrolysis products after 3 min of treatment of 1 g of particleboard at 573 K.

however a little difference most probably due to the presence of 10% of UF resin.

3.2. Determination of the optimum duration of treatment as a function of the temperature

The breakdown products of the urea-formaldehyde or melamine-formaldehyde resins at temperatures lower than 623 K are mainly N-compound such as isocyanic acid and ammonia [8]. Indeed, the results given by spectrometer FTIR reveal the presence of these two nitrogenized gases. Fig. 3 shows the spectrum of pyrolysis gases after 3 min of treatment of 1 g of melaminated particleboard (pyrolysis at 573 K under nitrogen (2 L/min)) where we can distinguish the peaks corresponding to ammonia and to isocyanic acid. It also appears that cyanhydric acid is not produced at this temperature.

The qualitative analysis during the low temperature pyrolysis reveals the production of many compounds which can be classified as follows:

- The non-condensable gases such as CO, CO_2 and CH_4. Light hydrocarbons are not produced at such a low temperature.
- The condensable gases which contain water and primary tars such as acetic and formic acid (coming from the degradation of cellulose and hemicelluloses [19]), methanol (coming from the methoxy groups (–OCH3) of the lignin) and N-compounds such as ammonia and isocyanic acid.

After a numerical treatment of the different spectra recorded during each experiment, the evolution of the level of NH_3 and isocyanic acid in the pyrolysis gases can be showed on graphs for different temperatures (see Figs. 4a and b and 5a and b).

We can observe that the levels of ammonia and isocyanic acid increase quickly in the first minutes of treatment, what shows the performance of the process. These levels decrease almost so quickly in the following minutes to reach a value close to zero higher the temperature of treatment, the shorter the time needed for the treatment.

A first objective of this study is to evaluate the optimum time of treatment according to its temperature.

Concerning the evolution of the ammonia, the treatment duration is set to the duration necessary for the ammonia percentage to reach a value lower than 100 ppm. For the evolution of the isocyanic acid, the treatment duration corresponds to the time requested for the rate of HNCO to reach a value lower than 3% of the maximum value reached in all tests. The results show that the isocyanic acid stays for a longer time in pyrolysis product. Thus, the optimum treatment duration is obtained from the evolution curves of the isocyanic acid level. Six couples ''time/temperature'' of treatment are thus determined. There are reported in Table 2.

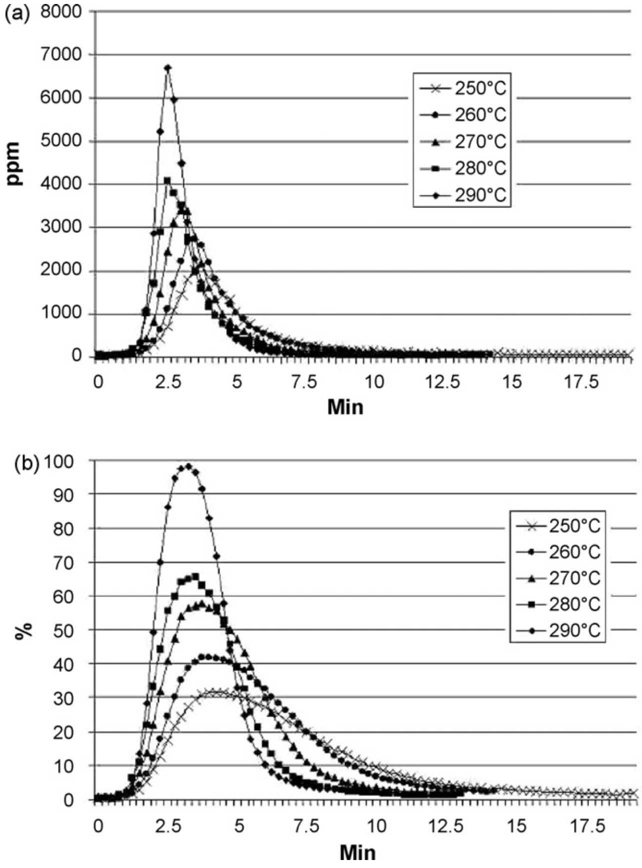

Fig. 4. (a) Evolution of NH_3 level in pyrolysis product during treatment of particleboard at different temperatures and (b) evolution of HNCO level in pyrolysis product during treatment of particleboard at different temperatures.

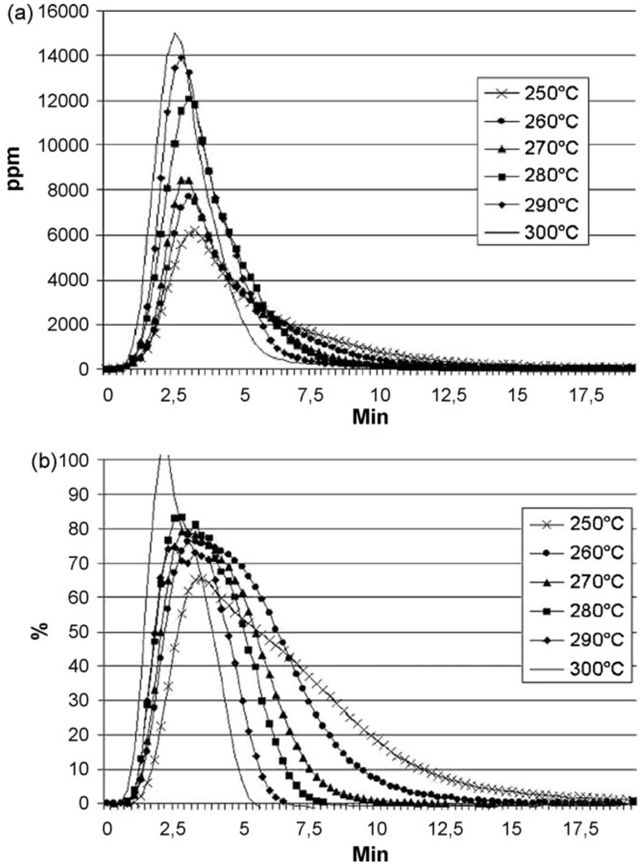

Fig. 5. (a) Evolution of NH_3 level in pyrolysis product during treatment of flooring at different temperatures and (b) evolution of HNCO level in pyrolysis product during treatment of flooring at different temperatures.

At low temperature, the time needed for the treatment of flooring is a bit shorter than for particleboard. This difference increases with the temperature. At 573 K, the time needed for particleboard treatment is 1.5 more than the one requested for treatment of flooring.

3.3. Volume of CO, CO_2, NH_3 and CH_4 produced during the treatment

Volumes of the different gases produced during each treatment are obtained by the method described before and are reported in Table 3. The volume of CH_4 is not discussed in this part as it is not produced in quantities big enough to be well measured. It can be noticed that the sum of the concentrations of the analysed three species never exceed 5% which means that the pyrolysis product flow can be considered as negligible.

Table 2
Optimal treatment time (min) in the temperature range between 523 and 573 K

T (K)	Particleboard	Flooring
523	14.5	14
533	13	11
543	11	9
553	9.5	7.5
563	9	6
573	8	5.5

Table 3
Gas amount produced during the optimal treatment time at each temperatures

	Volume (mL)			Mass (mg)		
	CO	CO_2	NH_3	CO	CO_2	NH_3
Particleboard						
523 K	2.7	9.4	12.2	3.4	18.5	9.3
533 K	3.1	10.3	13.4	3.9	20.2	10.2
543 K	4.3	14.2	14.6	5.4	27.9	11.1
553 K	5.2	15.9	11.2	6.5	31.2	8.5
563 K	7.6	20.3	16.7	9.5	39.9	12.7
573 K	10.5	40.4	12.3	13.1	79.4	9.3
Flooring						
523 K	2	20.3	11.6	2.5	39.9	8.8
533 K	2.55	22.2	11.8	3.2	43.6	9.0
543 K	3.2	26.1	12.1	4.0	51.3	9.2
553 K	5.1	29.1	11.1	6.4	57.2	8.4
563 K	6.2	32.4	10.5	7.8	63.6	8.0
573 K	8	40.8	10.3	10.0	80.1	7.8

It can be noticed that for both types of waste, the quantity of NH_3 volatilised during the treatment stay relatively constant and is between 8 and 10 mg what means that efficiency in terms of ‘‘nitrogen elimination’’ is not influenced by the treatment temperature.

However, the volume of CO increases to reach a value four times higher at 573 K than at 523 K what means that the energy recovery of the pre-treatment decreases with its temperature.

3.4. Mass of condensable gases produced during treatment of particleboard at 523 and 573 K

The measure of the mass of condensable gases produced during treatment allows evaluating the mass balance in order to check if our results are coherent. All values needed for the evaluation of the mass balance are reported in Table 4.

Without the mass of condensable gases, the mass balance reaches around 80 wt% for the different cases which means that the mass of condensable gases is not negligible. In order to better close the mass balance, the mass of condensable gases is measured. This measure is made only for particleboard treated at 523 and 573 K as it is just done in order to check the coherence of the results. In this case, a glass fibre tissue trap (Fig. 1) kept at 273 K is set up between the reactor and the gas cell. For the two cases where the mass of condensable gases is measured, the mass balance reaches between 92 and 94 wt% which means that almost all compounds generated during the first step are measured. The mass balance would be improved with quantifying the isocyanic acid.

The part of particleboard converted to condensable gases (water + primary tars) is three times higher at 573 K than at 523 K. This increase cannot be only attributed to the increase of the production of water. In this way, these results show that a larger quantity of primary tars is produced, implying a loss of combustible matter.

Table 4
Mass and proportion of gas, char and condensable gases produced during the optimal treatment time at each temperatures

mg/%	Dry mass sample	Measured gases	Char	Condensable gases[a]	Balance (%)
Particleboard					
523 K	930/100	31.1/3.3	780/83.9	48.5/5.2	92.4
533 K	930/100	34.3/3.7	740/79.6		83.3
543 K	930/100	44.3/4.8	725/74.7		82.7
553 K	930/100	46.2/5	695/72		79.7
563 K	930/100	62/6.7	670/68.3		78.7
573 K	930/100	101.8/10.9	635/68.3	146/15.7	94.9
Flooring					
523 K	935/100	51.2/5.5	735/78.6		84.1
533 K	935/100	55.8/6	730/78.1		84.0
543 K	935/100	64.5/6.9	715/76.5		83.4
553 K	935/100	72/7.7	705/75.4		83.1
563 K	935/100	79.4/8.5	690/73.8		82.3
573 K	935/100	98/10.5	660/70.6		81.1

[a] The mass of condensable gases corresponds to the mass of condensable gases measured with the glass fiber tissue trap minus the mass of water present in the initial wet sample (70 mg as humidity is 7%).

3.5. *Efficiency of the process*

3.5.1. *Elementary analysis of residues*

The elementary analysis (see Table 5) will now allow estimating the efficiency of each process. Levels of devolatilisation of different constituents such as N, C, H, O are deduced from the results of the elementary analysis and from the level of degradation of the samples after each treatment. Fig. 6a shows that the level of devolatilisation of nitrogen, in the case of particleboard, is around 56% and is relatively constant. These results show that the performance of the process from a ‘‘nitrogen elimination’’ point of view is not influenced by the treatment temperature for particleboard.

In the case of flooring, we can see in Fig. 6b that the level of devolatilisation is less constant than for particleboard. The average of this level is around 46% which is lower than for particleboard.

Table 5
Elementary analysis of residues treated at different temperatures

	C	H	N	O	Residual mass percentage
Particleboard					
Non-treated	47.97	6.6	4.29	41.04	100
523 K	51.32	5.68	2.3	39	78
533 K	52.45	5.56	2.71	39.12	74
543 K	52.95	5.66	2.25	37.33	72.5
553 K	52.09	5.39	3.25	38.33	69.5
563 K	54.59	5.51	2.46	37.26	67
573 K	56.4	5.61	2.15	35.72	63.5
Flooring					
Non-treated	45.06	6.18	5.25	41.38	100
523 K	50.09	5.76	2.41	39.34	73.5
533 K	50.29	5.68	3.9	37.8	73
543 K	51.42	5.58	3.56	35.95	71.5
553 K	51.11	5.5	5.07	36.27	70.5
563 K	51.22	5.51	3.97	36.33	69
573 K	52.42	5.44	3.91	35.71	66

These results mean that the ‘‘char’’ produced during the first step cannot be considered as ‘‘clean’’, the way of the classical gasification for the second step of the process, thus, does not appear as the best solution. We can then privilege the way of fast pyrolysis. A non-oxidative atmosphere may help to keep the nitrogen in the char and to produce a gas with the less N-compounds as possible. Nevertheless, nitrogen contained in the char will be also converted to pollutants if the char is burned to supply energy for the process. A valorisation of the material could be, then, discussed for this ultimate waste.

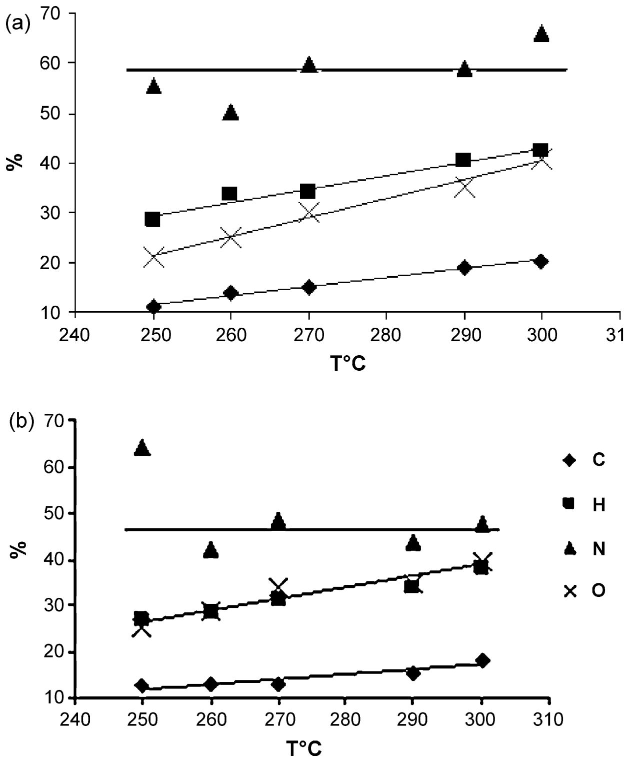

Fig. 6. (a) Evolution of C, H, N, O devolatilised during treatment of particleboard at different temperatures and (b) evolution of C, H, N, O devolatilised during treatment of flooring at different temperatures.

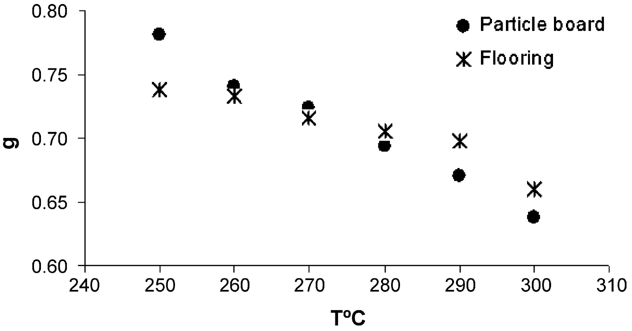

Fig. 7. Evolution of residual weight after treatment at different temperatures of 1 g of sample.

In the same way, the quantities of carbon, oxygen and hydrogen volatilised during the treatment increase with temperature (in both cases), which may imply a loss of combustible material.

The study of the quantity of CO produced during each treatment (given by integrating the evolution curves of the level of CO in the pyrolysis products) confirms the latest results as the volumes of CO increase with temperature especially above 553 K. The study of the level of degradation of samples during different treatments will confirm this result.

3.5.2. Evolution of the level of degradation of samples with the treatment temperature

After each treatment, the weight of residue is measured in order to determine a degradation level for each couple "duration/temperature" of the treatment. The evolution of the weight of residue with the temperature can be observed in Fig. 7. Despite the decrease of the duration of treatment together with the increase of temperature, the degradation level of waste increases with the treatment temperature. These results show that an increase of the treatment temperature may imply a loss of material.

Thermal analysis of residues in a calorimetric bomb will allow evaluating the energy contained in residues after treatment and determining the energy recovery of treatment at each temperature.

3.5.3. Thermal analysis of the residues

Several experiments in a calorimetric bomb enabled to measure the high heating value (HHV) of residues. The LHV is deduced from the HHV value and from the elementary analysis results (the yield of hydrogen is needed).

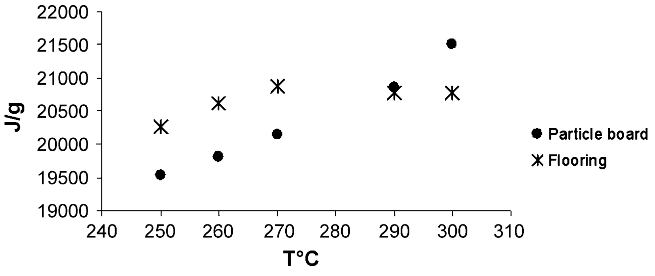

Fig. 8. Evolution of LHV of residues related to the temperature of treatment.

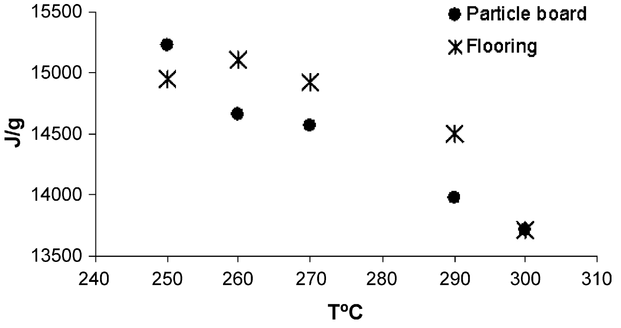

Fig. 9. Evolution of energy recoverable in 1 g of wet sample according to the temperature of treatment.

As we can see in Fig. 8, the LHV of residues, coming from particleboard, increases with increasing temperatures of the process. Indeed, the level of carbon increases while the rate of oxygen decreases with the temperature (results given by elementary analysis), which explains the results obtained.

For the flooring, LHV values remain steady.

Two trends can be observed on a thermal point of view: the higher the temperature is, the higher is the level of degradation of the sample but the more the residue is energetic. The quantity of energy contained in the residue is obtained by multiplying the LHV of the residue by its weight after the treatment. The results are reported in Fig. 9. We can see that the higher the temperature is, the lower is the quantity of energy contained in the residue. This decrease of the quantity of energy remains moderate in the range of temperatures studied.

The energy recovery of the process is, thus, influenced by the type of treatment. However, considering that carbon monoxide and condensable gases, evolved from the low temperature pyrolysis, can be burnt (after gas cleaning) to supply energy for the process, the energy recovery of the different types of treatment can be improved and re-equilibrated. The aim of this process is to produce a "clean" combustible and not heat, indeed, the low temperature conditions have to be privileged. Nevertheless, since some energy has to be supplied to the process, the optimal treatment temperature can be set to produce enough combustible gases to supply energy for the process. This optimization of the conditions of the process could be determined by a study on an industrial reactor.

4. Conclusion

Experiments prove that UF and MF resin are responsible for the production of nitrogen compounds as ammonia and isocyanic acid but that no cyanhydric acid is produced for temperatures from 523 to 573 K.

In this range of temperatures, the optimum times of treatment vary from 15 to 5 min and are a bit shorter for the flooring treatment.

We show that the efficiency of the process in terms of nitrogen elimination is not influenced by the type of treatment.

Nevertheless, temperatures of the treatment influence:

- the level of degradation of waste, which increases with temperature;

- the LHV of the residues, which increases with temperature;
- the energy recovery (energy contained in the residue/initial energy contained in waste), which decreases with temperature.

The energy recovery of the different types of treatment can be improved and re-equilibrated by considering the energy contained in the carbon monoxide and in the condensable gases (which have a non-negligible fuel value) produced during the low temperature pyrolysis.

Elementary analysis shows that this process assumes to eliminate around 58 wt% (particleboard) and 46 wt% (flooring) of the nitrogen initially present in the waste which shows the limit of this cleaning. Nevertheless, the thermal valorisation (gasification or pyrolysis) of the pre-treated particleboard will produce lower volumes of pollutants than virgin particleboard which shows the interest of the process. Some experiments about the gasification of the obtained residue will be performed in our lab.

Acknowledgements

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References

[1] C. Martin-Biegalke, Dégradation par l'eau et la chaleur des résines Urée-Formol; PhD Université Henri Poincaré, Nancy 1 (1993).

[2] T. Hirata, S. Kawamoto, A. Okuro, J. Appl. Polym. Sci. 42/12 (1991) 3147–3163.

[3] P. Girods, A. Dufour, Y. Rogaume, C. Rogaume, A. Zoulalian, in: Proceedings of the 2nd International Green Energy Conference, Oshawa, Ontario, Canada, June 25–29, 2006.

[4] Thurner, Mann, Ind. Eng. Chem. Process Des. Dev. 20 (1981) 482–488.

[5] J.M. Antal, in: K.W. Boer, J.A. Duffie (Eds.), Advances in Solar Energy, vol. 1, American Solar Energy Society, Boulder, CO, 1982 , pp. 61–111.

[6] J.M. Antal, in: K.W. Boer, J.A. Duffie (Eds.), Advances in Solar Energy, vol. 2, American Solar Energy Society, Boulder, CO, 1985, pp. 175–255.

[7] Fengel, Wegener, Wood: Chemistry, Ultrastructure, Reactions, Walter de Gruyter, Berlin, New York, 1984.

[8] W. Quirino, Valorisation énergétique des déchets de bois par pyrolyse étagée, PhD Université Henri Poincaré, Nancy 1, 2000.

[9] C. Schanzer, H.G. Buehrer, Spectrosc. Eur. 14/6 (2002) 21–23.

[10] L. Helsen, E. Van den Bulck, J. Anal. Appl. Pyrol. 53 (2000) 51–79.

[11] L. Helsen, E. Van den Bulck, S. Mullens, J. Mullens, J. Anal. Appl. Pyrol. 52 (1999) 65–86.

[12] J. Reina, E. Velo, L. Puigjaner, Ind. Eng. Chem. Res. 37 (1998) 4290–4295.

[13] M.J. Antal, H. Friedman, F. Roger, Comb. Sci Technol. 21 (1980) 141–155.

[14] T.H. Liou, F.W. Chang, J.J. lo, Ind. Chem. Res. 36 (1997) 568–573.

[15] L. Becker, G. Matuschek, D. Lenoir, A. Kettrup, J. Anal. Appl. Pyrol. 57 (2001) 15–36.

[16] F. Shafizadeh, Thermal Uses and Properties of Carbohydrates and Lignins, Academic press, New York, San Fransisco, London, 1976.

[17] C. Di Blasi, J. Anal. Appl. Pyrol. 47 (1998) 43–64.

[18] N. Grioui, K. Halouani, A. Zoulalian, F. Halouani, Thermochim. Acta 440 (2006) 23–30.

[19] X. Déglise, Les conversions thermochimiques du bois, Revue Forestière Française, XXXIV (4) (1982) 249–270.